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Ultrasonic wave propagation in [210] direction in silicon

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1. Introduction

Waves propagating through silicon crystal show birefringence, the phenomenon in which an incident wave is splitted into two or more waves [1, 2]. Propagation properties of those waves created by birefringence can be determined theoretically by Christoffel's equation if the information about the medium and the incident direction is known. The Christoffel's equation is set up by organizing the Newton's law and the Hooke's law in 3 dimension. The propagating direction and the vibrating direction are parallel for the longitudinal wave and perpendicular for the transverse wave. The wave whose propagating direction and vibrating direction are neither parallel nor perpendicular is called quasi waves.

In the present work, we theoretically predict and experimentally confirm the propagation properties of waves on silicon crystal. Specially, we focus on the quasi transverse wave propagating in [210] direction.

2. Theory

The propagation speed and the vibrating direction of the wave propagating through silicon crystal can be calculated by the Christoffel's equation. Mostly, the equation gives one or two transverse waves with one longitudinal wave for silicon crystal [3].

Quasi waves are categorized into quasi transverse wave and quasi longitudinal wave according to the difference of angle between the propagation direction and the vibrating direction. **Fig.1** shows quasi difference for the quasi transverse wave propagating in [ab0] direction. It can be shown from **Fig.1** that the quasi difference has greatest value, which is about 7.3°, between [210] direction and [310] direction. In this research, we take [210] direction for observation.

The quasi transverse wave propagating through the silicon crystal has its vibrating direction parallel to the surface of the medium and its propagation direction slightly askew from the perpendicular line to the surface. When it is reflected from the surface parallel to its vibrating direction, it returns to the original wave source [3].

Fig.2 demonstrates the propagation and the reflection of the quasi wave.

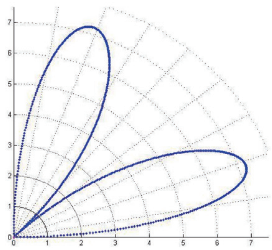

Fig.1 Quasi difference(°) of the quasi transverse wave propagating in [ab0] direction.
*(r,θ) = (angle deviation(°), direction)

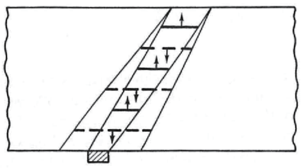

Fig.2 Oblique reflection of quasi wave in an anisotropic solid with parallel sides[3]

3. Method

3.1 Silicon crystal cutting

Since quasi transverse wave is formed when the wave propagates in [210] direction, the perpendicular line to the wave front should be 7.13° askew from the [210] direction. We used water jet to cut the silicon into a solid with two parallel sides, which are 1.55 cm apart.

3.2 Confirmation of the reflection point

According to the solution of the Christoffel's equation for the wave propagating in [210] direction, three waves are formed: one transverse wave, one quasi transverse wave, and one quasi longitudinal wave. The quasi transverse wave propagates at the speed of 5060 m/s.

Transverse wave probe of 10 MHz are used in this experiment. The transmission probe is attached to the center of one side and the receiver proves moves along the other side. The signal amplitude of the quasi transverse wave is recorded as the receiver probe travels along the side in the step of 2 mm in order to determine the reflection point of the quasi transverse wave.

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3.3 Birefringence in [210] direction

In this research, we focus on the propagation two shear waves. The incident transverse wave, propagating in [210] direction and vibrating in arbitrary direction, is generated by 10 MHz shear wave probe. Then, the 10 MHz shear wave probe on the other side senses two shear waves, formed by birefringence and records their time durations and amplitudes. Since speeds of the quasi transverse wave and the transverse wave are 5060 m/s and 5843 m/s respectively, those waves are expected to be detected around 6.2 μs and 5.3 μs. Vibrating direction of the incident wave varies from [001] to $[\bar{1}20]$. Therefore, the transmission probe rotates total 90° and the data is collected for every 10° rotation. Eventually, from the data collected, we examine how the birefringence happens according to the vibrating direction of the incident wave.

4. Result

4.1 Confirmation of the reflection point

The receiver moving along the side of the silicon solid recorded the amplitude of the 10MHz quasi transverse wave generated by the transmitter on the other side. amplitudes of each part were recorded and graphed according to their angles from the transmitter. **Fig.3** shows the comparison between experimentally recorded amplitude and theoretically predicted amplitude.

The maximum peak of the signal appears around 9.76° from the transmitter. This is 2.63° askew from the predicted value. The data recorded for angles either smaller than -6° or larger than 29° can be inaccurate since the signal was blended with noise.

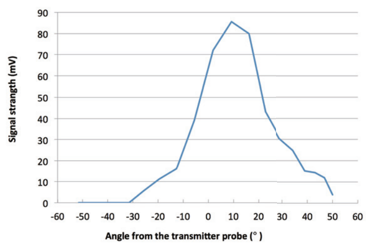

Fig.3 Amplitude according to the angle from the transmitter probe.

4.2 Birefringence in [210] direction

The probe recorded time duration, which the wave it generated took to reflect at the other side and reach back to it. The quasi transverse wave and the transverse wave were detected at 6.1 μs and 5.2 μs, which are both 0.1 μs different from expected. **Fig.4** demonstrates signals of two waves on the oscilloscope display. The quasi transverse wave and the transverse wave are indicated with arrows in **Fig.4**; the left arrow points to the transverse wave at 5.2 μs, and the right arrow points to the quasi transverse wave at 6.1 μs. **Fig.5** shows the amplitude of the transverse wave divided by the amplitude of the quasi transverse wave. The data was recorded every 10° rotation of the probe vibrating from [001] direction to $[\bar{1}20]$ direction. The amplitude of the transverse wave and that of the quasi transverse wave get stronger as the vibrating direction of the probe gets closer to [001] direction and $[\bar{1}20]$ direction, respectively.

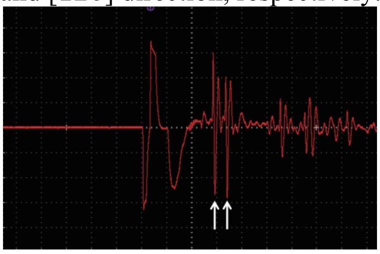

Fig.4 Signals of the transverse wave(left) and the quasi transverse wave(right).

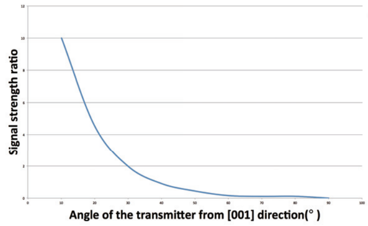

Fig.5 Ratio of amplitude of the transverse wave to that of the quasi transverse wave.

5. Conclusion

In this research, we examined the propagation property of 10 MHz wave in [210] direction in silicon crystal. Reflection point of the quasi transverse wave was predicted and confirmed by experimentation. Also, the ratio of amplitude of the transverse wave to the quasi transverse wave as probe rotates from [001] direction to $[\bar{1}20]$ direction was examined.

Acknowledgment

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